

PHOTON AND NUCLEON INDUCED PRODUCTION OF Θ^+

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We investigate Θ^+ production via photon and nucleon induced reactions. We observe that the positive parity Θ^+ production provides about ten times larger total cross sections than those of the negative parity one in both photon and nucleon induced reactions due to P -wave enhancement of the $KN\Theta$ vertex. We also consider the model independent method in the nucleon induced reaction to determine the parity of Θ^+ and show clearly distinguishable signals for the two parities.

1. Introduction

After the observation of the evidence of Θ^+ by LEPS collaboration¹ motivated by Diakonov *et al.*², physics of exotic pentaquark baryon state has been scrutinized by huge amount of research activities. In the present work, we investigate Θ^+ production via photon and nucleon induced reactions using Born diagrams with a pseudoscalar K and vector K^* -exchange included. For the nucleon induced reaction, we consider the model independent method to determine the parity of Θ^+ which has not been confirmed yet by experiments. In calculations, we assume that Θ^+ has the quantum numbers of spin 1/2, isospin 0 and the decay width $\Gamma_{\Theta \rightarrow KN} = 15$ MeV is used to obtain $KN\Theta$ coupling constant^{1,2}. We perform calculations for both parities of Θ^+ .

2. Photon induced reactions: $\gamma N \rightarrow \bar{K}\Theta^+$

In this section, we study the total cross sections of $\gamma N \rightarrow \bar{K}\Theta^+$ reactions. Results are given in Fig 1. Two models are employed for the $KN\Theta$ cou-

pling schemes. One is the pseudo-scalar (PS, thick lines) and the other is pseudo-vector (PV, thin lines) to investigate theoretical ambiguity. As for the anomalous magnetic moment of Θ^+ , κ_Θ , we employ -0.8 considering several model calculations^{3,4}. We set the unknown $K^*N\Theta$ coupling constant to be $|g_{KN\Theta}|/2$ with positive (dashed line) and negative signs (dot-dashed line). In order to take into account the baryon structure, we employ a gauge invariant form factor which suppresses s - and u -channels³. In Fig.1 we plot total cross sections of the neutron (left) and proton (right) targets only for the positive parity Θ^+ since we observe that the overall shapes and tendencies for the negative parity Θ^+ are quite similar to the positive parity one. A major difference between them is that the total cross

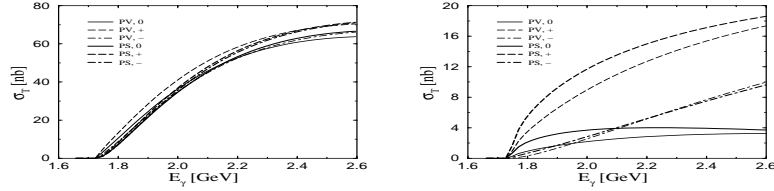


Figure 1. The total cross section of $\gamma n \rightarrow K^- \Theta^+$ (left) and $\gamma p \rightarrow \bar{K}^0 \Theta^+$ (right) for the positive parity.

sections are about ten times larger for the positive parity Θ^+ than for the negative parity one due to the P -wave coupling nature of the $KN\Theta$ vertex. We also find that theoretical ambiguities due to the PV and PS schemes, κ_Θ and K^* -exchange contribution become small for the neutron target where the t -channel K -exchange dominates, whereas we find large model dependence for the proton case, where the K -exchange does not appear.

3. Nucleon induced reactions: $np \rightarrow Y\Theta^+$ and $\bar{p}\bar{p} \rightarrow \Sigma^+\Theta^+$

In this section we investigate NN scattering for the production of Θ^+ . Here, we make use of the Nijmegen potential⁵ for the KNY coupling constants. We also take into account K^* -exchange contributions with vector and tensor $K^*N\Theta(Y)$ couplings⁶. We consider only $Y = \Lambda$ since overall behaviors of $np \rightarrow \Sigma^0\Theta^+$ are similar to $np \rightarrow \Lambda\Theta^+$ with differences in the order of magnitudes of the total cross sections ($\sigma_\Lambda \sim 5 \times \sigma_{\Sigma^0}$). We employ a monopole type form factor with a cutoff mass 1.0 GeV⁶. In Fig.2 we plot the total cross sections for the reaction with two different parities of Θ^+ . We observe that difference in the magnitudes of the total cross sections

for the two parities is similar to the photoproduction. Furthermore, the results are not very sensitive to the signs of vector and tensor $K^*N\Theta$ coupling constants. The labels in parenthesis denote $(\text{sgn}(g_{K^*N\Theta}^V), \text{sgn}(g_{K^*N\Theta}^T))$. We note that if we consider initial state interaction, the order of magnitudes will be reduced by about factor three ^{6,7}. As suggested by Thomas *et al.* ⁸, tak-

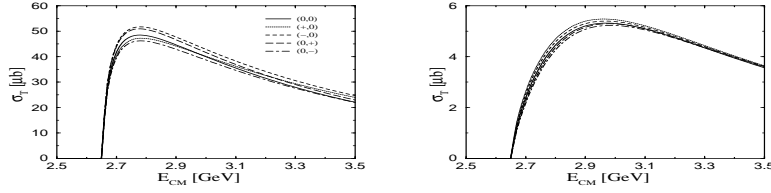


Figure 2. Total cross sections of $np \rightarrow \Lambda\Theta^+$ for the positive (left) and negative (right) parities of Θ^+ .

ing into account the Pauli principle and parity conservation, $\vec{p}\vec{p} \rightarrow \Sigma^+\Theta^+$ provides a clear method for the determination of the parity of Θ^+ . Spin 0 initial state allows non-zero production rate near the threshold (S -wave) for the positive parity Θ^+ , while spin 1 initial state does for the negative parity one. This selection rule should not be affected by any model dependences. We confirm that at the threshold region (~ 2730 MeV), the reaction process is dominated by S -wave so that the selection rule is applicable ⁹. We observe clear evidences of the selection rule in Fig. 3. K^* -exchange

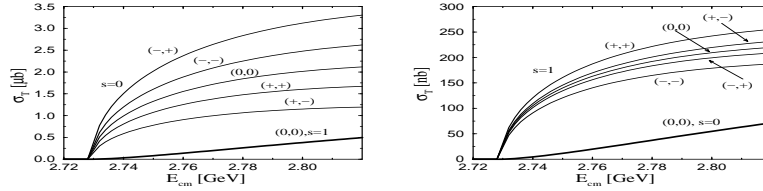
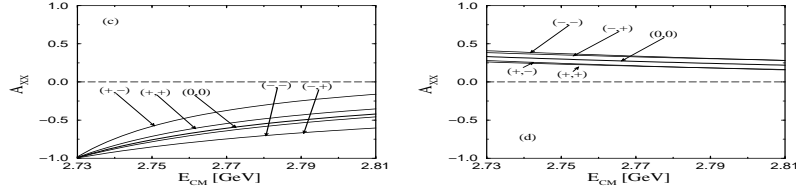


Figure 3. Total cross sections of $\vec{p}\vec{p} \rightarrow \Sigma^+\Theta^+$ for the different spin states, spin 0 and spin 1 and for the positive (left) and negative (right) parities of Θ^+ .

contribution is not so sensitive to the various sign combinations. The spin observable A_{XX} , which was suggested by Hanhart *et al.* ¹⁰ is plotted in Fig. 4. Up to about 100 MeV above the threshold, the results of the two different parities of Θ^+ show clear difference due to the selection rule ^{9,10}.

Figure 4. A_{XX} for the positive (left) and negative (right) Θ^+ .

4. Summary

We have investigated the photon and nucleon induced reactions for the Θ^+ production in Born diagram calculations with appropriate form factors and with some phenomenologically determined coupling constants. Due to the different $KN\Theta$ vertex structure, we observed about ten times larger total cross sections for the positive parity Θ^+ . Though we still have theoretical ambiguities, this property is quite universal for Θ^+ production reactions. The model independent method to determine the parity of Θ^+ via polarized pp scattering seems quite promising. As announced by COSY-TOF collaboration, we hope to see more experimental results from $\vec{p}\vec{p}$ scattering in the near future.

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